FILTRATION AND DEWATERING IN WASTEWATER TREATMENT

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Wastewater contains organic materials, nitrogen and phosphorus that are usually removed biologically, after which solids material is separated from the liquid in a clarifier or by a membrane. A by-product from biological treatment is excess sludge which has to be dewatered by using, for example, belt filters or sludge mineralization beds. Sludge is difficult to filter and the filtration rate does not increase with pressure due to high cake compressibility. However, a large variation is observed between different wastewater treatment plants.

In the work presented here the best dewaterability is observed for sludge that contains large strong compact flocs, without single cells and dissolved extracellular polymeric substances. Calcium ions improve floc strength and dewaterability, whereas sodium ions, for example from road salt, seawater intrusion and related industries, reduce dewaterability because the flocs tend to disintegrate at high conductivity. Storage lowers dewaterability, especially when storage takes place under anaerobic conditions. High shear has a tendency to destroy the flocs and reduce dewaterability. Thus, pumping and mixing should be done gently and in pipes without sharp bends.

INTRODUCTION

Municipal and industrial wastewaters contain high amounts of COD, nitrogen and phosphorus. These are usually removed biologically (the activated sludge process) after which the treated water has to be separated from the microbial materials. In a conventional activated sludge process this is done by using a clarifier, but alternatives exist. For example, a membrane bioreactor (MBR) can be used, where the membrane facilitates the required separation. The outcome of the process is treated wastewater (effluent) and excess sludge. The water content of the excess sludge is high and the excess sludge has to be dewatered before further handling, i.e. digestion for biogas production, transportation to agricultural fields or incineration. Different methods exist for dewatering including the belt filter, filter press, decanter centrifuge and sludge mineralization bed. Thus, several solid/liquid processes are involved in wastewater treatment, both for separating sludge from the treated wastewater and for sludge dewatering. The composition of the sludge is important for the separation processes, especially the properties of the sludge flocs.

This paper discusses filtration dewatering and how sludge properties affect the dewaterability. However, literature data shows that the sludge components which cause problems in filtration dewatering also cause problems in other types of separation processes. Thus, many of the conclusions from the paper are generally applicable to solid/liquid separation processes involving biological sludge.

SPECIFIC FILTRATE FLOW RATE

In conventional filtration theory, the liquid flow through a cake structure can be calculated using equation (1) if it is assumed that the filter medium resistance is negligible whereby:

$$q = \frac{p}{\mu \alpha_{av} \omega_c} \tag{1}$$

Here, q is the filtrate flux ($m^3/(m^2\ s)$), μ the filtrate viscosity (Pa s), p the filtration pressure (Pa), ω_c the mass of solid materials per unit filter medium area (kg/m^2), and α_{av} the average specific resistance (m/kg).

The average specific resistance is independent of filtration pressure for incompressible cakes. However, most cakes are compressible to some extent, i.e. the cake resistance increases with pressure. For sludge, the average specific resistance usually increases linearly with pressure[1]. In order to compare measured literature values of average specific resistance, it is necessary to know the filtration pressure. An alternative is to use the specific filtrate flow rate (SFF) which has been defined by Sørensen[1,2] as:

$$SFF = q\omega_c = \frac{p}{\mu \alpha_{av}} \tag{2}$$

Sørensen and Sørensen[1] found that the specific flow rate was constant for pressures above 2 kPa and equal to 7.0×10^{-6} kg/(m s) for sludge from Aalborg, Denmark. Further, specific filtrate flow rates have been measured from different wastewater treatment plants in Denmark, and these data show that the flow rate varies by a factor of 10 (Figure 1)[3]. Thus, sludge composition has a significant impact on sludge dewaterability and in order to understand how different sludge properties affect the specific filtrate flow rate, cake compression will be discussed in more detail in what follows.

SLUDGE CAKE COMPRESSIBILITY

Several studies have been done to study cake compression. Chu and Lee[4] have investigated the consolidation of sludge cakes and found three consolidation stages which were ascribed to three different compression mechanisms (see Table 1).

Both primary and secondary consolidation is observed for inorganic particles[5], and the description of cake compression due to collapse of the global structure and particle migration agrees well with the theory presented in Tiller and Yeh[6] and the experimental data in Channel *et al.*[7]. For organic particles consisting of soft water-swollen materials, deformation and compression of individual particles is also important. A study of synthetic polystyrene-co-poly(acrylic acid) shows that the soft polyacrylic acid shell deforms and compresses during filtration, which lowers the specific flow rate by a factor of 10-100 because the soft materials fill out the void space between the particles[8].

A relatively large reduction in cake water content is observed during the consolidation of both sludge and synthetic particles[9]. Hence, compression and deformation of individual particles may explain the high compressibility for sludge. Other parameters that are important during the filtration and compression of sludge filter cakes include floc disruption and erosion[10]. Furthermore, biological degradation of the material may affect cake properties. Thus, not only are particle size, the degree of aggregation and structure important for dewaterability, but so are water content of the flocs and floc strength.

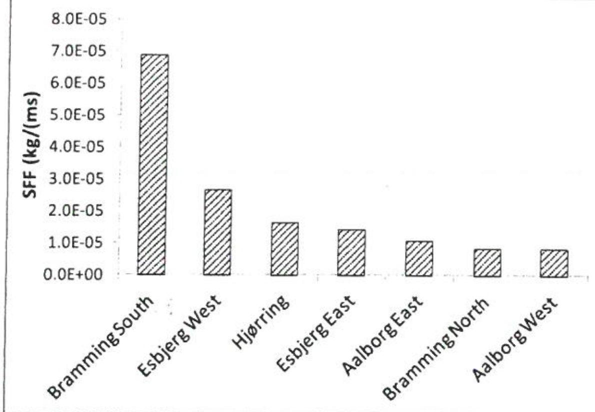

Figure 1: Specific filtrate flow rate for seven different wastewater treatment plants in Denmark, data recalculated from[3].

SLUDGE COMPOSITION

Biological sludge contains flocs, filaments, single cells and extracellular polymeric substances (EPS). The flocs consist of microorganisms, filamentous bacteria, organic fibres, inorganic particles (salt and sand), and extracellular polymeric substances (EPS); a typical size of the flocs is 40-125 µm[11]. A sketch of a typical sludge floc is shown in Figure 2. The structure can vary a lot from large compact flocs (the ideal floc), flocs with a high amount of filamentous bacteria (filamentous bulking), or small light flocs without filamentous bacteria (pinpoint floc). In some plants no flocs are formed (dispersed growth) and the sludge mainly consists of single cells (1-10 µm) and EPS (typically protein, polysaccharides and humic like substances).

Generally, the best separation properties are obtained if the sludge contains large compact flocs, and a low quantity or no single cells and EPS (Table 2). Such a scenario gives the best sedimentation in the clarifier, the highest permeate flux in a MBR system, the highest filterability (belt filters and sludge mineralization bed), the best effluent quality (decanter centrifuges) and a lower amount of required chemicals for sludge conditioning.

Several factors influence floc properties and the concentration of single cells and EPS. Not only is microbial growth important, but so is the physical-chemical properties of the inlet feed and the sludge, i.e. pH, ionic strength, and divalent ions. Furthermore, sludge handling is important for floc size and the number of single cells (Table 3).

IMPACT OF SALTS ON SLUDGE DEWATERABILITY

A high content of, for example, calcium (water hard-

Form of consolidation	Description
Primary	Collapse of global structure and dissipation of excess pore water
Secondary	Particle migration into a more stable configuration which requires particles to overcome the shear stress introduced by highly viscous surface absorbed water between the particles
Ternary	Deformation and compression of individual particles

Table 1: Consolidation stages according to Chu and Lee[4].

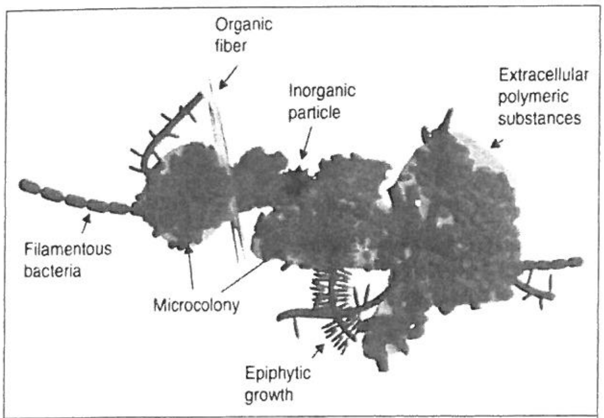

Figure 2: Schematic of sludge flocs (the ideal floc)[12].

ness) or other polyvalent cations improves dewaterability. The addition of ethylene glycol tetra-acetic acid (EGTA) removes calcium ions from sludge flocs which destabilizes the flocs, increases the concentration of single cells and EPS and thereby lowers the specific filtrate flow rate[13]. Also, an increased ratio between EPS and calcium/iron ions increases the concentration of single cells, lowers the floc size and lowers the specific filtrate flow rate[14]. High conductivity due to a high concentration of monovalent salt lowers the specific filtrate flow rate[13,15] which can be problematic in the North part of Europe due to road salting during winter. Furthermore, intrusion of seawater or salt from some types of industries increases sludge conductivity. The typical conductivity of Danish sludge is 750 µS/cm, but values up to 4400 µS/cm have been measured[16].

IMPACT OF STORAGE AND SHEAR ON SLUDGE PROPERTIES

Both storage and shear affect floc size and the number of single cells. A study of the anaerobic storage of sludge over a 10 day period shows a significant increase in the number of single cells and a reduction in specific flow rate by 80%[17]. Other studies show that the negative effect can be limited by ensuring aerobic or anoxic conditions during storage, for example, by aeration or the addition of nitrate[3].

Shear effects influence the sludge floc size as well and the specific flow rate is reduced after vigorous stirring[16,18]. Calcium reduces the effect of shear and reduces the adverse effects of anaerobic storage[16]. Thus, in order to ensure a high specific filtrate flow, gentle pumping, gently mixing, no storage in the tank and pipes, and no sharp pipe bends are advantageous.

CONCLUSIONS

A large variation in dewaterability is observed for different wastewater treatment plants; hence the sludge properties have a high impact on the specific filtrate flow rate. Sludge contains flocs, filaments, single cells, extracellular polymeric substances (EPS), and inorganic materials. The best dewaterability is observed for sludge that contains strong compact flocs and a low concentration of single cells and dissolved EPS. High water hardness improves dewaterability because calcium ions improve floc strength and reduce the concentration of single cells and EPS.

High conductivity reduces dewaterability as flocs disintegrate at high ionic strength. Thus, road salt in the winter season, intrusion of seawater and the production of salts from some types of industries can result in reduced dewaterability. Storage lowers dewaterability as flocs are caused to disintegrate and conductivity increases. Anaerobic storage, or tanks with anaerobic pockets, are more problematic than aerobic or anoxic storage. High shear in pumps and pipes tends to destroy flocs and reduces dewaterability, and should be avoid.

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Plant	Floc description (viewed via microscope)	Filaments	Relative SFF*
Bramming South	Large compact, round, dark flocs	1	100
Esbjerg West	Large, regular compact flocs	2	38
Hjørring	Medium sized flocs, both round, regular and open irregular	1	24
Esbjerg East	Open irregular, medium sized flocs	2.5	21
Aalborg East	Medium sized flocs, both compact and open	2	16
Bramming North	Very small irregular, disintegrated flocs, many branched filamentous bacteria	3.5	12
Aalborg West	Small, irregular flocs of open structure	2	12

Table 2: Sludge and floc properties[3]. *Relative SFF, obtained by setting Bramming South to 100.

Parameter	Effect
Conductivity	• Lowers specific flow rate • Can be a problem due to road salting, intrusion of seawater and salts from some industries
Hardness	• Improves specific flow rate • Calcium carbonate can be added to improved dewaterability
Storage	• Lowers specific flow rate • Anaerobic storage or tanks/pipes with anaerobic pockets are problematic • Aeration or the addition of nitrate during storage can improve filterability
Pumping	• Lowers specific flow rate • Gentle pumping and mixing • Avoid sharp bends on pipes
Treatment system	• Conventional plant usually gives better sludge than membrane bioreactors (MBR)

Table 3: Link between sludge treatment and dewaterability.

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